AFRL-RY-WP-TP-2010-1161

CROSS-LAYER BASED APPROACH FOR PRIMARY SIGNAL DETECTION IN WIRELESS COGNITIVE NETWORKS (PREPRINT)

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JUNE 2010

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YY)*	**2. REPORT TYPE**	**3. DATES COVERED *(From - To)***
June 2010	Technical Paper Preprint	08 September 2006 – 31 August 2009

4. TITLE AND SUBTITLE
CROSS-LAYER BASED APPROACH FOR PRIMARY SIGNAL DETECTION IN WIRELESS COGNITIVE NETWORKS (PREPRINT)

5a. CONTRACT NUMBER
FA8650-05-D-1912-0007

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62204F

6. AUTHOR(S)
Y.B. Reddy

5d. PROJECT NUMBER
7622

5e. TASK NUMBER
11

5f. WORK UNIT NUMBER
7622110P

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Grambling State University
Dept of Mathematics and Computer Science
Grambling, LA 71245

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Sensors Directorate
Wright-Patterson Air Force Base, OH 45433-7320
Air Force Materiel Command
United States Air Force

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/RYRR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RY-WP-TP-2010-1161

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Technical paper for general release. PAO Case Number: WPAFB 08-0484; Clearance Date: 10 Oct 2008. Paper contains color.

This work was funded in whole or in part by Department of the Air Force contract FA8650-05-D-1912-0007. The U.S. Government has for itself and others acting on its behalf a paid-up, nonexclusive, irrevocable worldwide license to use, modify, reproduce, release, perform, display, or disclose the work by or on behalf of the U.S. Government.

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Cross-layer approach in cognitive wireless networks is proposed for efficient use of spectrum by detecting primary signals. The detection may be false detection of primary signal, missed detection of primary signal, or correct detection of primary signal. The quick and correct detection of primary signal will be helpful for utilization of the idle spectrum. In the current research, Su's algorithm [7] was modified and proposed the RASH (Random Access by Sequential search and Hash organization) algorithm for quick detection of idle channel. Further a new model was introduced using Drake's equation for primary signal detection. The simulation results show that the proposed model can detect the primary signal accurately and will be helpful for better utilization of the idle spectrum.

15. SUBJECT TERMS
cross-layer, primary signal, cognitive user, wireless networks, Quality of Service

16. SECURITY CLASSIFICATION OF: a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
Unclassified	Unclassified	Unclassified	SAR	12	Nivia Colon-Diaz
					19b. TELEPHONE NUMBER *(Include Area Code)*
					N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Cross-layer based Approach for Primary Signal Detection in Wireless Cognitive Networks

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ABSTRACT
Cross-layer approach in cognitive wireless networks is proposed for efficient use of spectrum by detecting primary signals. The detection may be false detection of primary signal, missed detection of primary signal, or correct detection of primary signal. The quick and correct detection of primary signal will be helpful for utilization of the idle spectrum. In the current research, Su's algorithm [7] was modified and proposed the RASH (Random Access by Sequential search and Hash organization) algorithm for quick detection of idle channel. Further a new model was introduced using Drake's equation for primary signal detection. The simulation results show that the proposed model can detect the primary signal accurately and will be helpful for better utilization of the idle spectrum.

KEYWORDS
cross-layer, primary signal, cognitive user, wireless networks, Quality of Service

1. Introduction

Communication systems are organized and divided into layers with well defined purposes. Each layer offers services to the respective higher layer. The standardized layered architecture is called the open systems implementation (OSI) model. The OSI model has been successful in providing modularity, flexibility, interchangeability, and standardization. Transmission communication protocol (TCP) has become the dominant communication protocol suite in today's multimedia applications. Internet protocol (IP) is a connectionless, best-effort-based, variable length, packet delivery network layer protocol that does not guarantee reliable and timely delivery of packets between end stations. TCP is a transport (layer 4) protocol that uses the basic IP services to provide applications with an end-to-end connection-oriented packet transport mechanism that ensures reliable and ordered delivery of data. TCP/IP protocol follows the OSI guidelines and is designed for point-to-point communication in wire-line communication systems. TCP has become the dominant communication protocol suite in today's multimedia applications. TCP is typically designed for fixed wired systems. In TCP, the packet loss may happen due to congestion.

Circumstances have changed with emergence of wireless communication environments. Wireless communication has become part of the daily life for most people in the world, particularly in developed areas. The services including email, web-based services, video conferencing, remote sensing, medical applications, air line reservations, and more services provided by the telecommunication companies are high in demand and difficult to satisfy the customers. Therefore, system developers and researchers face different problems in implementation to satisfy the customers. The problems in wireless networks include higher bit error rate (BER), multi signal propagation fading effects, interference problems from other stations, and other devices. To solve these problems, Transmission Communication Protocol (TCP) needs to depart from its original wired network oriented design and evolve to meet the challenges introduced by the wireless portion of the network.

The wireless networks can be categorized into totally wireless networks (mobile ad hoc networks) and wired-cum-wireless networks. In the wired-cum-wireless network, the wired network provides a high-speed backbone with the wireless LAN attached at the periphery of the wired network. The TCP performance affects the wireless medium due to limited bandwidth, long round trip times (longer latency delays), random transmission losses, handoff (user mobility), power consumption, and under utilization of network capacity. The transmission problems will increase with increase in number of customers.

Various models for efficient utilization of spectrum were proposed to meet the demands of customers and provide them with the quality of service (QoS) [1, 2, 3]. To guarantee the QoS in wireless networks, link adaptation techniques have been widely considered as the key solution to improve the efficiency of power and bandwidth [4] at physical layer (PHY). Considering the link adaptation at the upper protocol layers such as data-link layer and application layer will greatly improve the spectrum utilization. After exploring the dependencies and interactions between layers, it was understood that optimum performance and QoS can be obtained by sharing information across the layers of protocol stack and the potentially powerful results of adaptive cross-layer design (CLD) approaches.

The cross-layer approach violates the traditional layered architecture, since it requires new interfaces, merges adjacent layers, and shares key variables among multiple layers. So, we must select the CLD approach without modifying the current status of the traditional layered architecture. But, the CLD without solid architectural guidelines leads to the spaghetti-design. Furthermore, different kinds of CLD design proposals raise different implementation concerns. In wireless communications, the first implementation concern is direct communication between layers through the creation of new interfaces for information sharing. The second concern proposes a common entity acting as a mediator between layers. The third depicts completely new abstractions. The combination of second and third concerns will pose a new design without disturbing the original layered design of wireless networks.

Unutilized spectrum can be detected by using multiple sensors at each secondary user. Ma et al. [5] proposed dynamic open spectrum sharing MAC protocol by using separate set of transceivers to operate on the control channel, data channel, and busy-tine channel, respectively. Hsu et al. [6] proposed the cognitive MAC with statistical channel allocation. In their approach, the secondary users select the highest successful transmission probability channel to send the packets based on channel statistics. They further identify the unused spectrum and highest successful transmission statistics with higher computational complexity. All these approaches require more computational time and resources. Alternatively, unutilized spectrum can be identified by tuning the transceivers through special algorithm (s) and allocating the spectrum without interfering with the primary user (PU). Su and Zhang [7] proposed algorithms for random sensing and negotiation-based channel sensing policies without centralized controllers. Su claimed their proposal performs better in identifying unused spectrum.

The rest of this paper is organized as follows: primary user detection techniques are discussed in the section 2. Section 3 discusses the problem formulation with improved performance algorithm, time duration for idle channel, channel utilization, Drake's equation, and channel utilization using Drake's equation. Section 4 discusses the simulations and the conclusions, future research is provided in section 5.

2. Primary User Detection Techniques

The primary objective of cognitive radio is to detect the spectrum holes (unused spectrum) and act quickly to utilize that unused spectrum. The secondary objective is to detect the presence of primary signal (user) quickly. Early detection avoids harmful interference to the primary user and efficient use of unused spectrum at any time. Currently there are many techniques to detect the presence of primary signal. The following are some of the techniques:

- Energy Detectors – measures the signal strength in the input wave over specific interval [8]. False detection is possible due to the presence of noise.
- Matched filter – cognitive radios obtain the information from physical layer (PHY) and medium access control (MAC) layer. The information includes modulation type and order, pulse shaping, packet format, etc. The matched filtering technique requires less time to detect the primary signal, since it uses few selected samples [9].
- Feature detection – detects primary signals using cyclostationary signal processing through sampling, scanning, and modulation [10]. The detection may fail due to shadowing or fading effects.
- Cooperative spectrum sensing – a better sensing technique which uses multiple cognitive radios cooperatively to avoid shadowing [11, 12, 13].
- Adaptive filtering in mud pulse telemetry – uses a mud pulse telemetry adaptive noise canceller to detect the presence of primary signal. The process "uses combination of a transmitted pulse and a reflected pulse, and the reference transducer receives a reference signal based on the transmitted pulse. The ANC linearly relates the secondary signal to the primary signal by means of a fast recursive least squares algorithm and calculates a set of weighting coefficients. The finite impulse response (FIR) filter of the ANC uses the set of weighting coefficients to adaptively noise cancel correlated portions between the primary signal and the secondary signal to produce an ANC output signal based on uncorrelated portions between the primary signal and the secondary signal" [16].
- Spectrum sensing in IEEE 802.22 – a spectrum correlation based peak detection method to check the presence of primary signal [17].

In addition, there are many hybrid techniques used to detect the primary signal [14, 15]. In [14] more than one user cooperates at entry and exit of primary user to minimize false alarms. Gudmundson [15] proposed the auto correlation model for received signal in shadow fading mobile radio system, which is good only for moderate and large cells.

3. Problem Formulation

In the proposed CLD, we assume that each cognitive user has control transceiver (CT) and software designed radio (SDR) transceiver. The control transceiver obtains information about the un-used licensed channels and negotiates with the other secondary users through the contention-based algorithms, such as the 802.11 distributed coordination function (DCF) and carrier sense multiple access (CSMA) protocols. The SDR transceiver tunes to any one of the *n* licensed channels to sense for free spectrum and receive/transmit the secondary users' packets. The SDR transceiver further uses carrier sense multiple access with collision detection (CSMA/CD) protocol to avoid the packet collisions.

We assumed that there are *n* channels in a licensed spectrum band. The control channel must find the unused channels among these channels at any given time. There are many ways to find the unused channels. The controller can poll randomly and find the unused channels. Probability of finding the unused channel is 1/n. The secondary user may wait till the particular channel becomes available or alternatively, it can negotiate for free channel or combination of these methods. All these methods take time to find a free channel for cognitive user. If there are m cognitive users and number of trials equals m times n (m*n). Therefore, an alternative approach faster than current models is needed to find free channel for cognitive user to transmit the packets.

The proposed approach has two steps. In the first step secondary users sense the primary channels and send the beacons about channel state. The control transceiver then negotiates with other secondary users to avoid the collision before sending the packets. Since each secondary user is equipped with one SDR, it can sense one channel at a time and do not know the status of all channels. The goal is to show the status of all licensed channels. So, we propose an algorithm called Random Access by Sequential search and Hash organization (RASH). RASH is similar to sequence search and alignment by hashing algorithm (SSAHA) approach [19] for faster search and identify the idle channel. Using RASH, the primary channels are hashed into G groups with a tag bit as part of the hash head (bucket address). The flag bit (bucket bit) is in on/off state depending on if any channel in the group is idle (bit is on) or if all channels are busy (bit is off). The value of G is calculated as G = n/m. Now, each secondary user uses its SDR transceiver to sense one hashed head to find the idle channel. If the flag bit is off, then there is no need to search the bucket for free channel. If the flag bit is on the sequential search continues to find the free channel or channels (if the bucket size is chosen very large, alternative search methods are required). The RASH algorithm is in two parts and given below:

3.1. Pseudo code for cognitive user to identify idle channel at MAC protocol

The report part of the algorithm developed by su [7] is modified for faster access. The Negotiation phase is not modified. The modified report part is given below:

Report the idle channel

BN =Bucket Number; ICN= Idle channel number=0;
LIC – List of idle channels=0

A. Control transceiver – listens on control channel
   Upon receive on K^{th} mini-slot (bucket number)
   Store the bucket number BN=bn;
   //update the number of unused channels List of unused channels
   C=0 //number of channel in the bucket

```
While (C!= EOL) do  //end of list
 {
   If (C=idle) then {
     ++ICN;
            //increase the number of idle channels
      LIC= BN*K+C;
            //Slot number or channel number
        }
   }
```

B. SDR transceiver –Receive the list of idle channels
   Send the beacon to each idle channel in LIC using sensing policy
   Confirm and report the idle channels to control transceiver

See reference [7] for Negotiating Phase.

3.2. Time Duration to Identify an Idle Channel

The time duration of the time slot in the proposed RASH algorithm is calculated as follows:

Let T_d be the time duration of the time slot, T_{rp} be reporting phase, and T_{np} be negotiation phase. The time duration is given by [7]

$$T_d = T_{rp} + T_{np}$$

The reporting phase is divided into bucket report and identification of idle channel or channels. Therefore, time reporting phase is written as

$$T_{rp} = B_{rp} + C_{rp}$$

// B_{rp} = bucket report and C_{rp} = channel report

For example, if there are 1000 channels and each bucket contains 11 channels, the probability of finding the bucket is 1/91, and probability of finding the channel in the bucket is 1/11. Therefore, the probability of finding the idle channel is 102/1001 or 102/1000 (approximately) whereas, the probability of finding the idle channel in random selection [7] is 1/1000. The results show RASH can find idle channels faster than random selection. Similarly, we can calculate the probability of channel utilization.

3.3. Channel Utilization

It is important for cognitive user to calculate the idle time of the channel utilized by the primary signal. The idle time will be better utilized by the cognitive user during the absence of primary user. Assuming that the number of times channel is *on* is the same as number of times the channel is *off*, then the total time utilization by any channel is calculated as:

$$T_{ct} = C_{it} + C_{ut} + C_{nc} \times (T_{on} + T_{off}) \text{ ----- } (1)$$

Where

T_{ct} = Total channel time

C_{it} = channel idle time

C_{ut} = channel utilization time

C_{nc} = number of times position change (on to off or off to on)

T_{on} = time taken to bring channel to on state

T_{off} = time take to bring the channel to off state

If the channel is on completely in a given time slot then the probability of channel utilization is 1, otherwise the probability of channel utilization time is

$$P_{cut} = \frac{1 - P_{cit} - \delta}{T_{ct}} \quad \text{------} \quad (2)$$

Where

P_{cut} = probability of channel utilization

P_{cit} = probability of channel idle time

δ= channel on/of time which is very small and a constant

The value of P_{cut} is ≤ 1. Similarly, we can find for all channels the utilization time at any given time. The total idle time of all channels for any licensed spectrum band of *n* channels is sum of idle time of n channels. If we assume the probability of channel utilization is average channel utilization time, then the probability of presence of primary signal P_{ps} at any given time slot is

$$P_{ps} = \frac{P_{cut}}{P_{tct}} \quad \text{------} \quad (3)$$

Where

P_{tct} is the probability of total channel time (time slot that channel can have).

The channel utilization will be calculated using Drake's equation in the next subsection.

3.4. Drake equation

Let N_{ac} be the primary signals that occupy the spectrum space at any time and can be detected (if they are within the range of energy detectors of our CRs). If they are outside the range of our energy detector appointed by the CRs, the signals can not be detected. At any time, we can observe the presence of signals as none, few, or more. The value of N_{ac} is calculated with the well known Drake equation [18]

$$N_{ac} = R^{*} f_p\, n_e\, f_l\, f_i\, f_c\, L \quad \text{-----} \quad (4)$$

The variables in the above equation may be interpreted in the current situation as:

R^* = the average rate of PU activation (formation) in the specified spectrum space
f_p = fraction of those PUs that occupied the spectrum
n_e = average number of PUs that are potentially supported by spectrum
f_l = fraction of those channels that will come in contact of ED (energy detector)
f_i = fraction of those have highly detectable signals
f_c = fraction of those PUs that have detectable signals
L = Length of time the primary signals release detectable signals

Note that the probability of space occupied by the primary signals at any time is less than or equal to 100%. Better detection will be available by having higher values of N_{ac} that occupy the spectrum space. If 60% primary signals occupy the spectrum, then sum of f_l, f_i, f_c must be equal to 60%. If average number of PUs potentially supported by the spectrum is approximately 50% (percentage can vary), then N_{ac} depends upon product of R* and L. The product of the values of these two variables must be a large number so that N_{ac} is greater than 2. For example, let us assume that the value of N_{ac} varies 1 to 100 (maximum occupation 100%). Then the probability of signal detection will be faster as the value N_{ac} increases. The results are shown in simulations using MATLAB language.

3.5. Channel Utilization using Drake's Equation

Let Pr be the probability of primary signal at the cognitive domain, then for each primary signal

$$P_r = K * P_{ps} * P_{cut} \quad \text{------} \quad (5)$$

Where K is an arbitrary constant and can have adjustable value (0<K<1). Now consider that all primary signals that are transmitting at the same time may or may not be detected. The probability of the signal that never be detected is

$$P_{nd} = 1 - P_r \quad \text{-----} \quad (6)$$

From the equation (6) we calculate that the probability of all primary signals that never be detected (P_{pnd}) cognitive base. The value will be calculated by repeating the equation (6) N_{ac} times.

$$P_{pnd} = P_{nd} \times P_{nd} \times ... \times P_{nd}\,(N_{ac} times)$$

$$P_{pnd} = P_{nd}^{N_{ac}} \quad \text{-----} \quad (7)$$

Since P_{pnd} is less than 1, P_{pnd} gets smaller as N_{ac} gets bigger. This is exactly we require. If we properly detect the presence of primary signal, we can utilize the idle time of primary signal or signals. Therefore, the probability of detecting the primary signal is

$$P = 1 - P_{pnd} \quad \text{-----} \quad (8)$$

$$P = 1 - (1 - K \times P_{ps} \times P_{cut})^{N_{ac}} \quad \text{----} \quad (9)$$

P will be closer to 1 as N_{ac} becomes larger. Equation (9) shows that for large values of N_{ac} , the primary signals are detectable and spectrum will be utilized efficiently by cognitive users. The efficient utilization of spectrum is subject to the condition that cognitive user identifies the idle channel efficiently using the RASH algorithm.

4. Simulations

Accurate detection of the primary signal means minimizing the false detections and missed detections. There are many factors that influence the detection. The factors include the length of time the primary signal releases, the Drake's constant, and the arbitrary constant. The product of constant, length of time primary signal release, and utilization of channel will make the factor $1 - K \times P_{ps} \times P_{cut}$ very small and exponentiation with N_{ac} will generate very small value which is required to detect primary signal accurately.

Figure 1 is drawn with K=0.3, length of primary signal release 60%, and utilization of channel =55%. The detection is 100% accurate for values of N_{ac} higher than 60. In Figure 2, with lower values of K and N_{ac}=60, the signal detection is better depending upon length of time the primary signal is released. This is not an acceptable condition for accurate detection of primary signal.

Figure 3 and Figure 4 show that by keeping the higher value K (K > 0.5) and N_{ac}, the signal detection can be done at the lower primary signal release time. Figure 5 shows that the effect of K value on signal detection.

The figures further show that failure to detect the primary signal access if K < 0.05, N_{ac} < 10, and length of release time < 0.2. This is possible only when sudden exit of more than one primary signal or similar interferences happen in the signal domain space. More simulations have been done for un-detectable cases, and we came to a conclusion that the proposed solution has higher detection rate of primary signal. The RASH algorithm with proposed solution will utilize the spectrum holes efficiently.

The results from the figures conclude that detection of primary signal depends on Drake's factor, arbitrary constant, and the length of primary signal release time.

5. Conclusions

The simulations show that the presence of primary signals, utilization of channels by primary signals, Drake's constant N_{ac}, and arbitrary constant K influence accurate detection of primary signal. For example, a value of N_{ac} = 60 and above has high influence on primary signal detection. If N_{ac} <60, then the constant K with value higher than 0.4 has similar effect on detection of primary signal. The values of N_{ac} and K affect more for higher probability of primary signal release and channel utilization. For lower probability of utilization, the N_{ac} and K have less effect on detection of primary signal. The simulations further conclude that we need alternative techniques to detect the primary signals when their presence is marginal.

Graphs

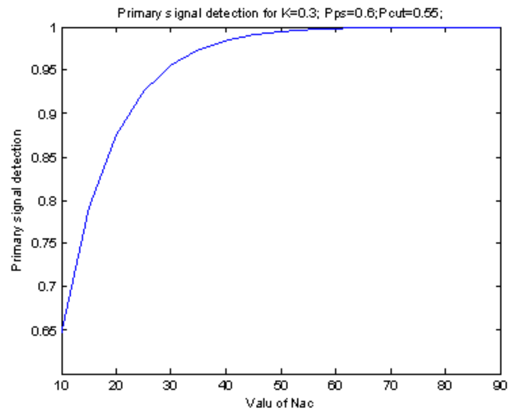

Figure 1: Detection of Primary Signal with N_{ac}=60, K=0.55

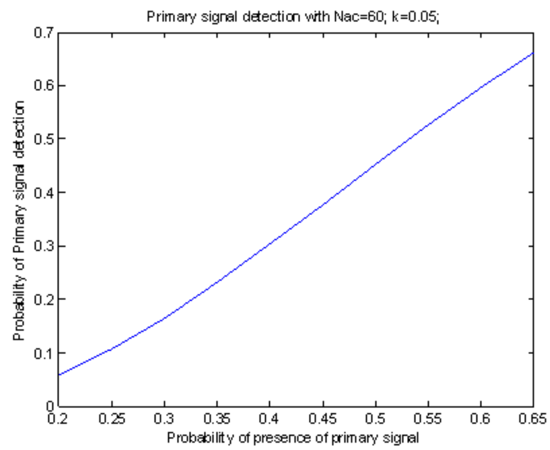

Figure 2: Detection of Primary Signal with N_{ac}=60, K=0.05

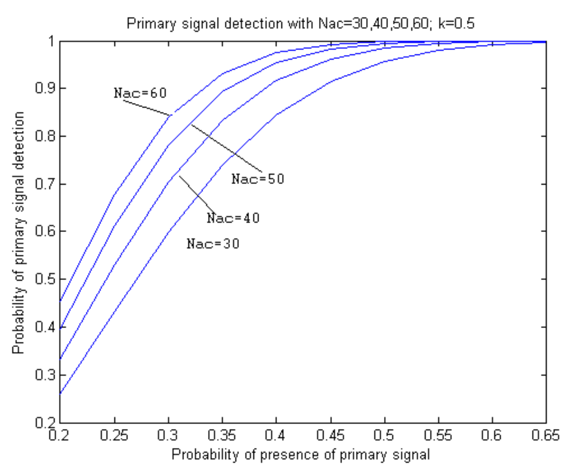

Figure 3: Detection of Primary Signal with N_{ac}= 30, 40, 50, 60 and K= 0.05

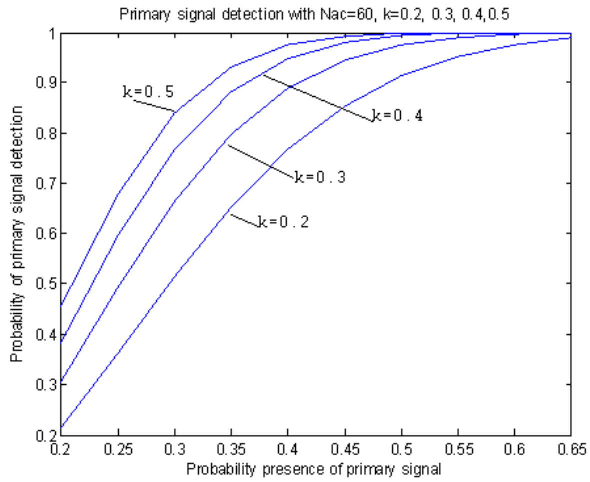

Figure 4: Detection of Primary Signal with N_{ac}= 60 and K=0.2, 0.3, 0.4, 0.5

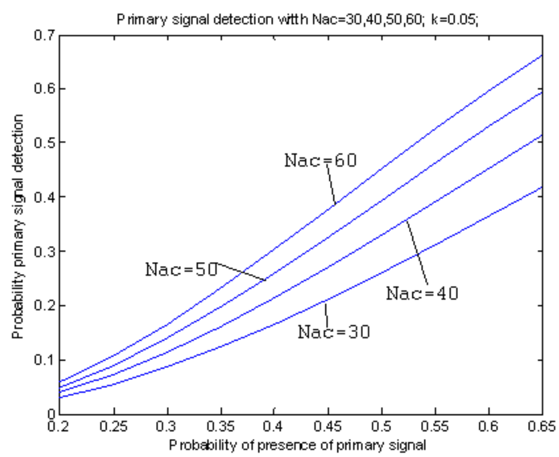

Figure 4: Detection of Primary Signal with N_{ac}= 30,40,50,60 and K=0.05

Acknowledgment

The research work was supported by Air Force Research Laboratory/Clarkson Minority Leaders Program through contract No: FA8650-05-D-1912. The author wishes to express appreciation to Dr. Connie Walton, Dean, College of Arts and Sciences, Grambling State University, for her continuous support.

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